MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2016/2017

ENT3076 – NANOSCIENCE

(NANO)

02 MARCH 2017
9:00 a.m. - 11:00 a.m.
(2 Hours)

INSTRUCTION TO STUDENTS

1. This Question paper consists of **5** pages including cover page with **FOUR** Questions only.

2. Attempt all **FOUR** questions. All questions carry equal marks and the distribution of the marks for each question is given.

3. Please print all your answers in the Answer Booklet provided.

List of Constants

Electron mass in free space, $m_o = 9.11\times 10^{-31}$ kg
One electron volt, (1eV) = 1.60×10^{-19} J
Electronic charge, $e = 1.60 \times 10^{-19}$ C
Planck's constant, $h = 6.63 \times 10^{-34}$ Js
Reduced Planck's constant, $\hbar = 1.05 \times 10^{-34}$ Js
Boltzmann constant, $k_B = 1.38 \times 10^{-23}$ JK^{-1}
Temperature in Kelvin, T(K) = T(°C) + 273 K
Permittivity of free space, $\varepsilon_o = 8.85 \times 10^{-14}$ Fcm^{-1}

List of Formulas

$$n = 1+\sqrt{\frac{2m^{*}V_bL^2}{\pi^2\hbar^2}}$$

$$\varepsilon_n = \frac{\hbar^2\pi^2}{2m^{*}L^2}n^2$$

$$\frac{\rho}{L} = \frac{1}{\pi}\sqrt{\frac{2m^{*}}{\hbar^2}}\sum_{n1,n2}\frac{1}{\sqrt{E-\varepsilon_{n1,n2}}}\Theta\left(E-\varepsilon_{n1,n2}\right)$$

$$\frac{\rho}{S} = \frac{m^{*}}{\pi\hbar^2}\sum\Theta\left(E-\varepsilon_n\right)$$

$$N_i = \frac{2\sqrt{2}m^{*\frac{3}{2}}}{3\pi^2\hbar^3}\left|V_b\right|^{\frac{3}{2}}L_xL_yL_z$$

Question 1

(a) Sketch the energy band diagram for both Type-I (straddling) and Type-III (broken gap) quantum wells. Discuss the difference of these quantum wells in confinement of carriers.

[6 marks]

(b) A quantum well based light emitting diode was fabricated using Indium Phosphide (InP) and Aluminium Nitride (AlN). Table Q1(b) listed the basic parameters of InP and AlN.

Table Q1(b)

Material	Electron Affinity (eV)	Energy Bandgap (eV)	Electron Effective Mass	Hole Effective Mass	Lattice Constant (Å)
InP	4.38	1.34	0.08 m_o	0.6 m_o	5.87
AlN	0.60	6.03	0.4 m_o	7.2 m_o	3.11

(i) With the aid of Table Q1(b), determine the minimum thickness of InP if 15 electron bound states are allowed in the quantum well. [4 marks]

(ii) Calculate the transverse motion energy of electron in the quantum well at energy level n=1, 2, 3 and 4. [6 marks]

(iii) Determine the density of states per unit area if the total energy of electron gas in the quantum well is 0.25eV. [5 marks]

(c) Draw the density of states for electrons in the quantum wire and quantum dot by assuming the dimension of all confinement directions are same. Label clearly the energy level for first 8 bound states in quatum wire and first 17 bound states in quantum dots. [4 marks]

Question 2

(a) Figure Q2(a) shows the reciprocal lattice for Material Q2. Give the definition of Brillouin zone and sketch the first, second and third order reduced Brillouin zone of the reciprocal lattice for Material Q2. [8 marks]

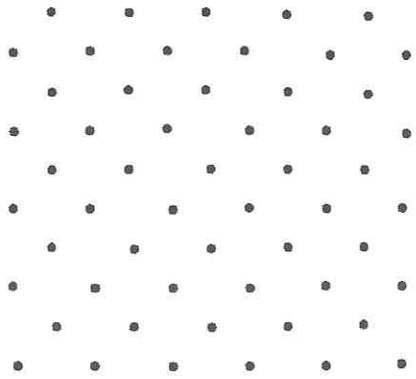

Figure Q2(a)

Continued ...

(b) (i) With the aid of graph and equation, explain the concept of electron effective mass. [5 marks]

(ii) Electron in L-valley of Gallium Arsenide (GaAs) has longitudinal effective mass at $1.9m_o$ and transverse effective mass at $0.075\ m_o$. Calculate electron effective mass for conductivity in L-valley of GaAs. [3 marks]

(c) Referring to the Table Q1(b) of Question 1, predict the defect at the interface of InP/AlN if the critical dimension, d_{cr}, is 10nm. Suggest 3 solutions to reduce this defect. [4 marks]

(d) Figure Q2(d) shows the changes of energy bandgap for Silicon-Germanium (Si_xGe_{1-x}) alloy. Briefly explain the phenomena happen while alloying Si and Ge. [5 marks]

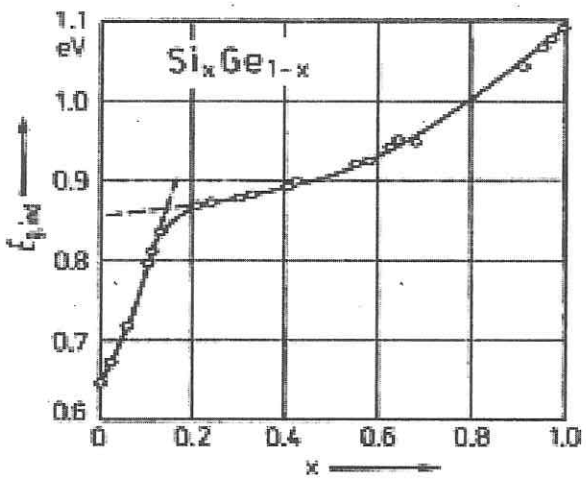

Figure Q2(d)

Question 3

(a) Differentiate parallel transport and perpendicular transport in a quantum wire. [8 marks]

(b) A double barrier tunneling diode is fabricated using AlN/InP quantum well structures as given in **Question 1**.

(i) Sketch the current-voltage (I-V) characteristics for this double barrier tunnelling structure and clearly label the conditions of the diode. [4 marks]

(ii) With the aid of simple energy band diagram, briefly explain the conditions of double barrier tunnelling diode in Question 3(b) (i). [9 marks]

(iii) Coherrent and sequential tunneling are two tunneling processes happen in double barrier tunneling diode. Explain the difference of both tunneling processes. [4 marks]

Continued...

Question 4

(a) With the aid of diagram, explain the effects of real-space transfer of hot electrons on total current density in a quantum well structure. [7 marks]

(b) (i) According to phototransition selection rules, calculate the first **THREE** allowed wavelength that can be emitted by the fabricated AlN /InP quantum well based light emitting diode in **Question 1**. [8 marks]

(ii) With the aid of diagram, briefly explain the phototransition selection rules. [6 marks]

(iii) Define intraband phototransitions and explain why it is allowed in quantum structures but forbidden in bulk crystals. Name the TWO processes of intraband phototransitions in quantum structure. [4 marks]

End of paper.